3.0 LANDFILL OFF-GAS CONTROL APPLICABILITY

This section describes the current technologies utilized for LFG emission control. The control techniques include LFG gas collection and disposal, LFG treatment for energy recovery, and condensate management. LFG control technologies are continually improving; however, the technologies described in this ETL are well established and can be found in industrial applications.

3.1 LFG COLLECTION

There are two gas collection strategies:- passive and active. A passive system functions on the principle that natural pressure gradient and convection mechanisms which move the LFG. Passive systems provide corridors to intercept lateral gas migration and channel the gas to a collection point or a vent. These systems use barriers to prevent migration past the interceptors and the perimeter of the landfill. Active systems move the LFG under induced negative pressure (vacuum). The zone of negative pressure created by the applied vacuum induces a pressure gradient towards a collection point which is either a well or horizontal collector pipe.

Detailed discussions of LFG collection system design can be found in Chapter 4, Design Considerations.

3.1.1 Comparison of Various Gas Collection Systems

The efficiency of a passive collection system depends on good containment of the LFG to prevent direct emission to the ambient air. Generally, passive collection systems have lower collection efficiencies than active systems, since they rely on natural pressure or concentration gradients to drive gas flow rather than a stronger, mechanically-induced pressure gradient. A well—designed passive system, however, can be nearly equivalent in collection efficiency to an active system if the landfill design includes synthetic liners in the landfill liner and cover.

Since a passive systems rely on venting, in the event that the vent is blocked by moisture or frost, the gas seeks other escape routes including moving into surrounding formations.

Passive systems are not considered reliable enough to provide an exclusive means of protection. With their concentrated vent gas, passive systems may be considered as an uncontrolled air emissions point source by regulatory agencies.

In addition, passive venting systems raise the potential for nuisance odor problems because there is no positive system for odor management.

The construction of passive systems is less critical than active systems, because the collection well is under positive pressure and air infiltration from the surface is not as great a concern. Additionally, elaborate well head assemblies are not required for passive systems since monitoring and adjustment are not usually necessary in these systems.

Active systems are usually utilized where a higher degree of system reliability is required than can be accomplished with a passive collection system. Based on theoretical evaluations, a well-designed active collection system is considered the most effective means of gas collection(3). Table A-5 presents a comparison of various gas collection systems.

3.2 LFG CONTROL TECHNOLOGIES

LFG can be either combusted with no energy recovery; combusted with energy recovery or purified for introduction to an off-site co-generation facility or release to atmosphere without treatment.

The non-energy recovery techniques use flares and thermal incinerators. The energy recovery techniques include gas turbines, internal combustion engines, and boiler-to-steam turbine systems, all of which generate electricity from the combustion of LFG. Boilers may also be used at the landfill site or off-site to recover energy from LFG in the form of steam.

TABLE A-5 COMPARISON OF VARIOUS COLLECTION SYSTEMS

Collection system type	Preferred applications	Advantages	Disadvantages
Active vertical well collection systems	Landfills employing cell-by-cell landfilling methods Landfills with natural depressions such as canyon	Cheaper or equivalent in costs when compared to horizontal trench systems	Difficult to install and operate on the active face of the landfill (may have to replace wells destroyed by heavy operative equipment.
Horizontal trench collection systems	Landfills employing layer-by-layer landfilling methods	Easy to install since drilling is not required	The bottom trench layer has higher tendency to collapse and difficult to repair once it collapses Has tendency to flood easily if water table is high Difficult to maintain uniform vacuum along the length (or width) of the landfill. Must be installed while the landfill is being constructed; not applicable for constructed landfills.
Passive collection systems	Landfills with good containment (side liners and cap)	Cheaper to install and maintain if only a few wells are required Lower in operation & maintenance cost	

Source: 3

3.2.1 Non-Energy Recovery

3.2.1.1 Flare

Flares are used at landfills as the main method of air emission control and as a back-up to an energy recovery system. Flaring is an open combustion process in which the 0_2 required for combustion is provided by either ambient air or forced air. LFG is conveyed to the flare through the collection header and transfer lines by one or more blowers. A knock-out drum is normally used to remove gas condensate. The LFG is usually passed through a water seal before going to the flare. This prevents possible flame flashbacks which occur when the gas flow rate to the flare is too low and the flame front moves down into the stack.

Two types of flare systems are generally available: open-flame flare and enclosed flare. Each flare type has advantages and disadvantages. Both types of flares have been used for LFG treatment.

Oven-Flame Flare. An open-flame flare or candle flare represents the first generation of flares. The open-flame flare was mainly used for safe disposal of combustible gas when emission control had not been a requirement. Open-flame flares have also been widely used in LFG combustion. Open-flame flare design and the conditions necessary to achieve 98 percent reduction of total hydrocarbon are described in 40 CFR 60.18.

The advantages of open-flame flares are:

- simple design since combustion control is not possible,
- ease of construction,
- most cost-effective way of safely disposing of landfill gases, and
- open-flame flares can be located at ground level or elevated.

The major disadvantage of all open-flame flares are:

- do not have the flexibility to allow temperature control, air control, or sampling of combustion products due to its basic design,

- not possible to design a closed-loop system to accurately measuring flow rates or emissions from an open-flame flare for the following reasons: 1) Sample probes placed too close to the flame will measure high $C0_2$ and hydrocarbon levels; 2) Samples taken further away from the flame are diluted unpredictably by air.

- if emissions sampling and testing are required, an enclosed type flare will be needed.

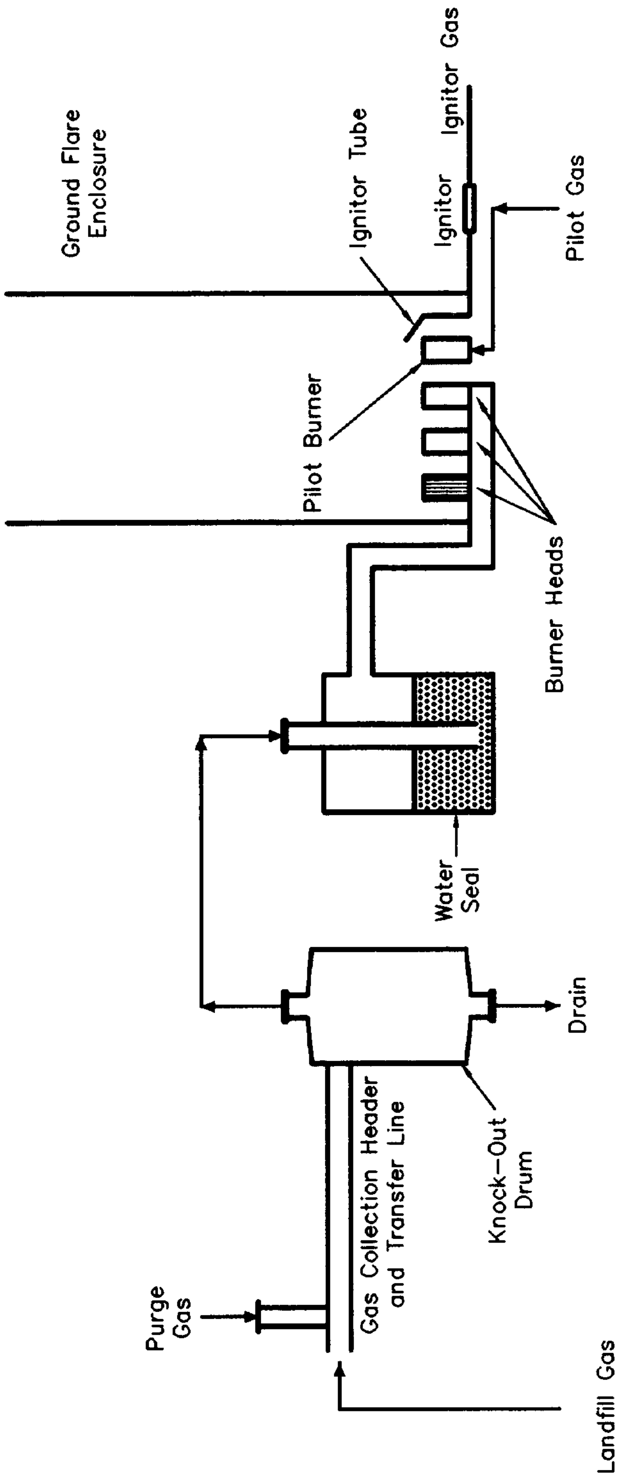
Enclosed Flares. Enclosed flares differ from open flares in that both LFG and air flows are controlled. While LFG is pushed through the flame arrestor and burner tips by a blower, the flare stack pulls or drafts the air through air dampers and around burner tips. The stack acts as a chimney, so its height and diameter are critical in developing sufficient draft and residence time for efficient operation. Enclosed flares are used in LFG applications for two reasons:

- They provide a simple means of hiding all or parts of the flame (i.e., neighbor friendly), and

- emission monitoring may be mandatory.

A typical enclosed flare system is shown in Figure A-4.

Depending on air regulations in each state, enclosed flares with an automatic air damper control may be required. Periodic sampling of these flares is conducted to ensure that an emission reduction of 98 percent is being achieved.



ENCLOSED FLARE SYSTEM

FIGURE A-4
(SOURCE 2)

3.2.1.2 Thermal Incineration

Thermal incineration processes use the basic operating principle of a thermal incinerator: any organic chemical heated to a high enough temperature in the presence of sufficient O_2 will be oxidized to CO_2 and water. The theoretical temperature required for thermal oxidation to occur depends on the structure of the chemical involved. Some chemicals are oxidized at temperatures much lower than others. Where thermal incinerators are used to control vent streams from LFG recovery systems, auxiliary fuel is typically required.

Thermal incinerators are applicable as a control device for any vent stream containing NMOCs. In the case of LFG emission, however, their use is primarily limited to control of vent streams from CH_4 recovery systems.

3.2.2 Energy Recovery Systems

In large municipal landfills, LFG is being developed as an energy resource. Military landfills, due to its size and waste types, usually do not generate methane gas in large quantity to be economically recovered. LFG in military landfills is therefore contained rather than recovered for energy use. Energy recovery options, however, are briefly discussed for the reader information.

The following four approaches have been adopted for recovering energy from LFG:

- Use of LFG to fuel gas turbine;
- Generation of electricity by the operation of an internal combustion engine with LFG;
- Use of LFG directly as a boiler fuel; and
- Upgrading the gas quality to pipeline quality for delivery to utility distribution systems.

Typical LFG contains approximately 500 Btu per standard cubic foot (4,450 K cal/m^3) of energy whereas pipeline-quality gas contains 1,000 Btu/scf (6,900 K cal/m^3). The energy content of LFG varies widely depending upon the performance of the gas collection system and the stage of decomposition within the landfill. Generally, the collection of gas for energy recovery purposes has been limited to large landfills with over 1 million tons of solid waste in place.

3.2.2.1 Gas Turbines

Process Description. Gas turbines aspire ambient air, compress it and combine it with fuel in the combustor. The combustor exhaust stream flows to the power turbine which burns the fuel to heat it, then expands it in the power turbine to develop shaft horsepower. This shaft power drives the inlet compressor and an electrical generator (or some other load).

Two basic types of gas turbines have been used in landfill applications: simple cycle and regenerative cycle. The gas temperatures from the power turbine range from 430 to 600^{0}C (800 to l,100^{0}F). The regenerative cycle gas turbine is essentially a simple cycle gas turbine with an added heat exchanger. Thermal energy is recovered from the hot exhaust gases and used to preheat the compressed air. Since less fuel is required to heat the compressed air to the turbine inlet temperature, the regenerative cycle improves the overall efficiency of the gas turbine(3).

Based on field tests and information provided by manufacturers, these turbines are capable of achieving greater than 98 percent destruction of NMOC.

Applicability. The applicability of gas turbines depends on the quantity of LFG generated, the availability of customers, the price of electricity, and environmental issues. There are about 20 landfills in the U.S. which employ gas-fired turbine(3).

Advantages of using gas turbines are:

- Gas turbines have lower emissions of NOx, CO and PM than comparatively sized of combustion engines;

- Gas turbines are less sensitive to fluctuations in influent Btu gas than are internal combustion engines;
- Using a dual oil and oil filter system, shutdowns for minor maintenance are less frequent;
- No gas condensate is formed in the process;
- Gas turbines are more mechanically reliable since they have fewer moving parts, no reciprocating moving parts, no valves, cams, belts, radiators, water cooling and ignition system (other than for starting); and
- Because there is no lube oil in the exhaust, air emissions are less than with internal combustion engines. Excess combustion air and high temperatures accomplish complete combustion of carbon monoxide and residual hydrocarbons.

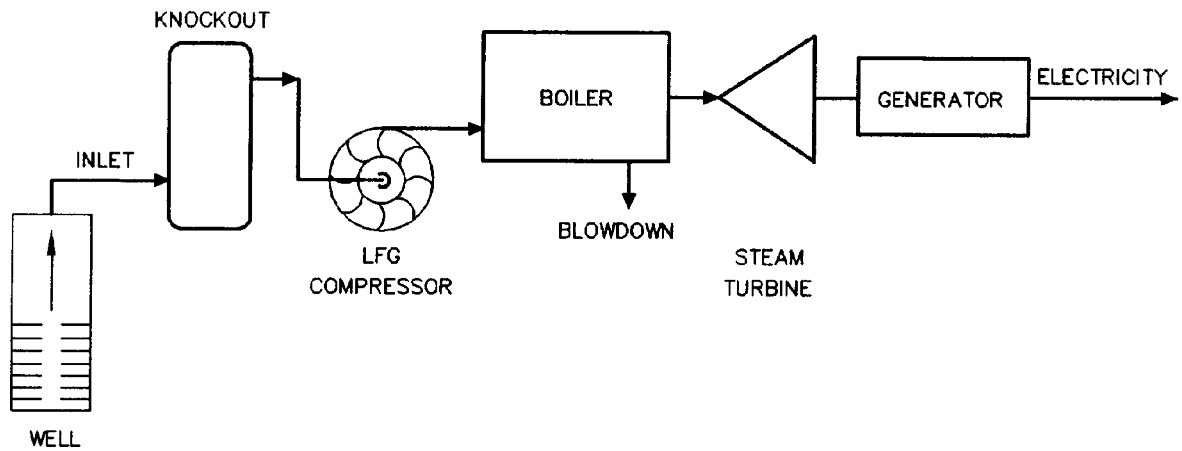
Disadvantages of using gas turbine engines are:

- O&M costs increase dramatically if the engine is used only intermittently (i.e., for peak power use);
- Turbine blades are sensitive to foreign particles in the gas and air streams;
- Oil deposits on blades can cause units to become unbalanced; and
- They require inlet compression of the fuel feed and air between 160 and 200 psig, thus ancillary compressor equipment is required.

A schematic of an LFG to steam generation plant is presented in Figure A-5.

3.2.2.2 <u>Internal Combustion (I.C.) Engines</u>

<u>Process Description</u>. Reciprocating internal combustion engines produce shaft power by confining a combustible mixture



SCHEMATIC OF LFG TO TURBINE ELECTRIC GENERATION
FIGURE A-5
(SOURCE 2)

in a small volume between the head of a piston and its surrounding cylinder, causing this mixture to burn, and allowing the resulting high pressure products of combustion gas to push the piston. Power is converted from linear to rotary form by means of a crankshaft[3].

The major problem with use of combustion engines for these applications is selection of the fuel gas compressor. Matching the gas compressor to the available gas and engine requirements is one of the major difficulties in the design of the completed gas-to-energy project. Many projects select the gas compressor by trial and error.

Applicability. I.C. engines are being used for landfill off-gas control because of their short construction time, ease of installation, and operating capability over a wide range of speeds and loads. I.C. engines fueled by LFG are available in capacities ranging from approximately 500 KW up to well over 3,000 KW.

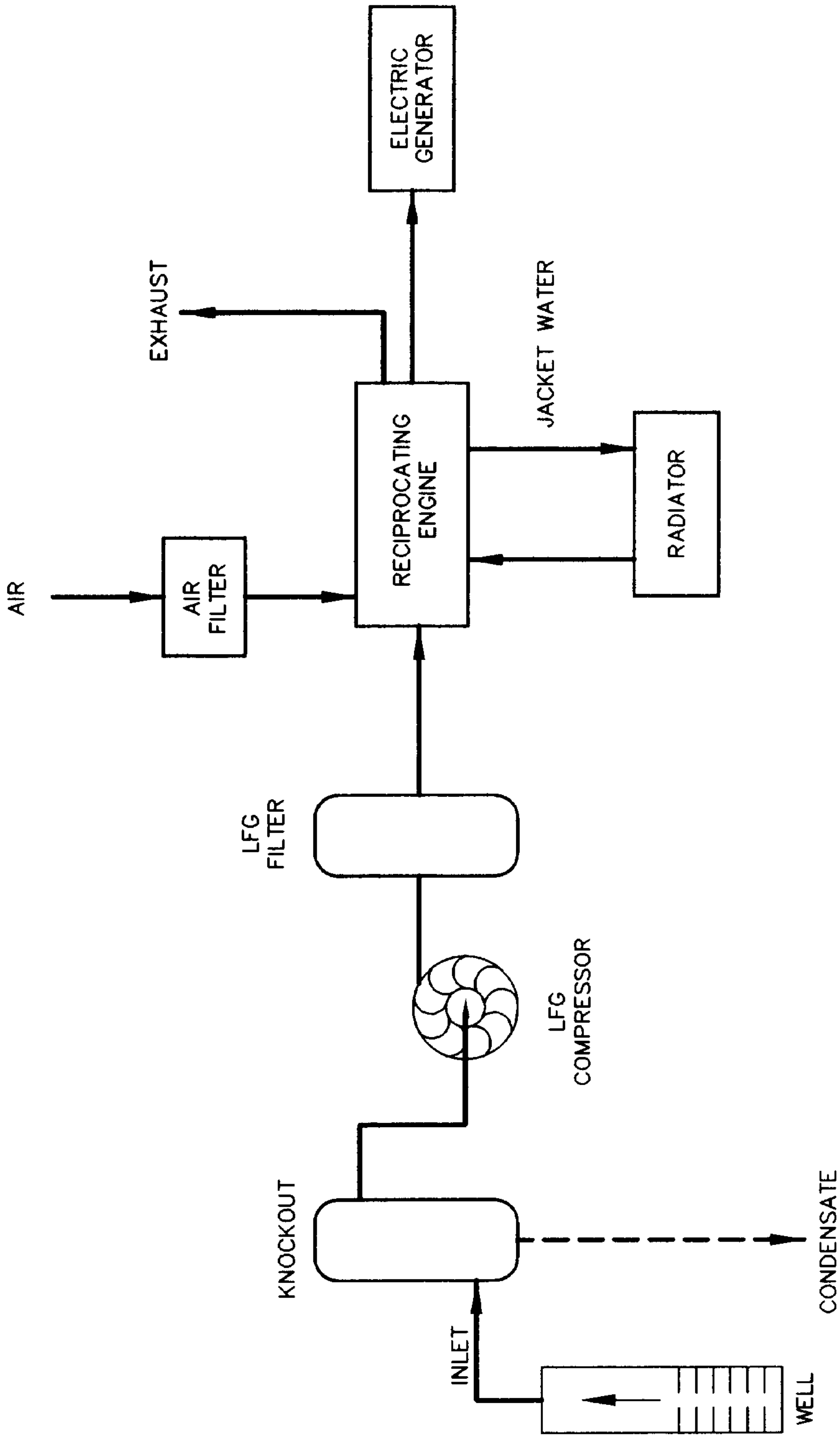
Advantages of using I.C. engines are:

- short construction time;
- can achieve 98 percent reduction of NMOC;
- NO_x emissions from these engines are lower than comparable natural gas fired engines;
- commonly used technology;
- wide range of availability; and
- efficient at full load and partial load.

Disadvantages of using I.C. engines are:

- the fuel gas compressor to match the I.C. engines;

A schematic of an LFG I.C. generation plant is presented in Figure A-6.



SCHEMATIC OF LFG TO INTERNAL COMBUSTION FOR ELECTRICAL GENERATION

FIGURE A-6

(SOURCE 2)

3.2.2.3 Boiler or Steam Generator

Process Description. The majority of industrial boilers are of water tube design. In a water tube boiler, hot combustion gases contact the outside of heat transfer tubes which contain hot water and steam. These tubes are interconnected by a set of drums that collect and store the heated water and steam. The water tubes are of relatively small diameter, 5 cm (2 inches), providing rapid heat transfer, rapid response to steam demands, and relatively high thermal efficiency. Energy transfer efficiency can be above 85 percent. Additional energy can be recovered from the flue gas by preheating combustion air in an air preheater or by preheating incoming boiler feed water in an economizer unit[3].

The majority of LFG-fired boilers are industrial boilers with corresponding heat inputs of approximately 10.5×10^6 Btu/hr (350 scfm at 50 percent CH_4) to 90×10^6 Btu/hr (3,000 scfm at 50percent CH_4). The most recent power generation technology to utilize LFG is the steam generator using the Rankine Cycle. The LFG is burned in a boiler to produce superheated steam. The steam drives a steam turbine generator for power production. The benefit of Rankine Cycle power production from the combustion of LFG is the low heat rate of 10,000 Btu/KW. This is the lowest rate and highest efficiency of all of the LFG-fired power generation systems to date. In addition, the Rankine Cycle has been demonstrated to be one of the lowest emitters of NO_x and ROG of any LFG-fired equipment.

Applicability. LFG-fired boilers may be utilized in two ways. The LFG may be routed to an on-site boiler or piped and sold to an off-site boiler to supply heat or hot water. The LFG may also be routed to an on-site boiler to generate steam to produce electricity.

Advantages of using LFG-fired boilers are:

- low NO_x emissions,
- small physical size, and

- low O&M cost.

Disadvantages of using LFG-fired boilers are:

- high initial capital investment,
- high fuel pressure required,
- inefficient at partial load, and
- large amount of condensate in the process.

3.2.2.4 LFG Purification Techniques

The LFG has a typical composition of 40 to 60 percent CH_4, 40 to 50 percent $C0_2$, 1 to 2 percent of air and inert gases and other impurities such as halogenated hydrocarbons, volatile solvents, organic sulfur compounds and H_2S. It is critical to almost all LFG end-usages that the CH_4 products be clean and not contain the impurities.

Purification techniques to upgrade the LFG to a high Btu value may include the followings:

- removal of impurities,

- removal of $C0_2$,

- removal of water, and

- gas compression to pipeline pressure.

Impurities removal techniques may include the use of adsorption, absorption or membranes to process raw LFG to pipeline quality natural gas. All purification techniques involve removal of water before removing $C0_2$. The water is removed by either absorption with glycol or adsorption with silica gel, alumina, or molecular sieves. The NMOC removal method depends on the different $C0_2$ removal techniques chosen and the composition of the LFG. Usually the same techniques used for $C0_2$ removal are also used to remove NMOC by simply adding an extra adsorption, absorption, or condensation step.

In general, the selection of a recovery technique depends on the gas generation rate, the location of the plant, the availability of a market for the recovered energy, and the environmental impacts.